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## (54) Derivation and quantization of robust non-local characteristics for blind watermarking

(57) An implementation of a technology is described herein for deriving robust non-local characteristics and quantizing such characteristics for blind watermarking of a digital good. This technology finds the proper balance between minimizing the probability of false alarms (i.e., detecting a non-existent watermark) and the probability of misses (i.e., failing to detect an existing watermark). The technology, described herein, performs quantization index modulation (QIM) based upon non-local characteristics of the digital good. Non-local characteristics may include statistics (e.g., averages, median) of a group of individual parts (e.g., pixels) of a digital good. This abstract itself is not intended to limit the scope of this patent. The scope of the present invention is pointed out in the appending claims.

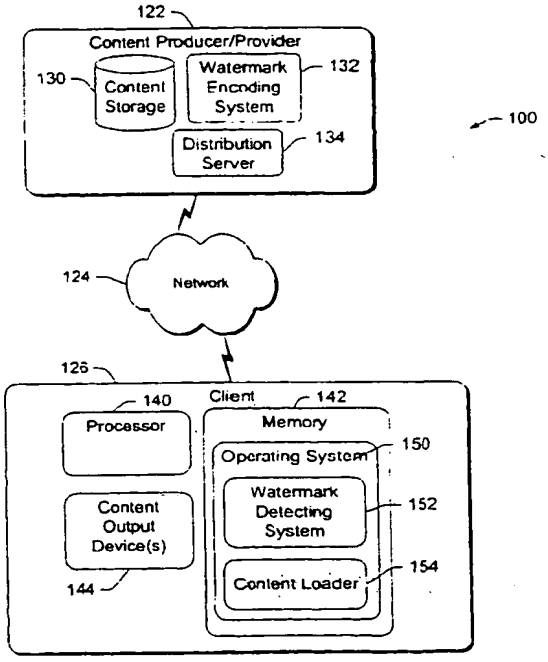


Fig. 1

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## Description

### TECHNICAL FIELD

**[0001]** This invention generally relates to a technology for deriving robust non-local characteristics and quantizing such characteristics for blind watermarking of a digital good.

### BACKGROUND

**[0002]** "Digital goods" is a generic label for electronically stored or transmitted content. Examples of digital goods include images, audio clips, video, digital film, multimedia, software, and data. Digital goods may also be called a "digital signal," "content signal," "digital bitstream," "media signal," "digital object," "object," and the like.

**[0003]** Digital goods are often distributed to consumers over private and public networks—such as Intranets and the Internet. In addition, these goods are distributed to consumers via fixed computer readable media; such as a compact disc (CD-ROM), digital versatile disc (DVD), soft magnetic diskette, or hard magnetic disk (e.g., a preloaded hard drive).

**[0004]** Unfortunately, it is relatively easy for a person to pirate the pristine digital content of a digital good at the expense and harm of the content owners—which includes the content author, publisher, developer, distributor, etc. The content-based industries (e.g., entertainment, music, film, etc.) that produce and distribute content are plagued by lost revenues due to digital piracy.

**[0005]** Modem digital pirates effectively rob content owners of their lawful compensation. Unless technology provides a mechanism to protect the rights of content owners, the creative community and culture will be impoverished.

### Watermarking

**[0006]** Watermarking is one of the most promising techniques for protecting the content owner's rights of a digital good (i.e., digital good). Generally, watermarking is a process of altering the digital good such that its perceptual characteristics are preserved. More specifically, a "watermark" is a pattern of bits inserted into a digital good that may be used to identify the content owners and/or the protected rights.

**[0007]** Watermarks are designed to be completely invisible or, more precisely, to be imperceptible to humans and statistical analysis tools. Ideally, a watermarked signal is perceptually identical to the original signal.

**[0008]** A watermark embedder (i.e., encoder) embeds a watermark into a digital good. It typically uses a secret key to embed the watermark. A watermark detector (i.e., decoder) extracts the watermark from the watermarked digital good.

#### Blind Watermarking

**[0009]** To detect the watermark, some watermarking techniques require access to the original unmarked digital good or to a pristine specimen of the marked digital good. Of course, these techniques are not desirable when the watermark detector is available publicly. If publicly available, then a malicious attacker may get access to the original unmarked digital good or to a pristine specimen of the marked digital good. Consequently, these types of techniques are not used for public detectors.

**[0010]** Alternatively, watermarking techniques are "blind." This means that they do not require access to the original unmarked digital good or to a pristine specimen of the marked digital good. Of course, these "blind" watermarking techniques are desirable when the watermark detector is publicly available.

#### Robustness

**[0011]** Before detection, a watermarked signal may undergo many possible changes by users and by the distribution environment. These changes may include unintentional modifications, such as noise and distortions. Moreover, the marked signal is often the subject of malicious attacks particularly aimed at disabling the detection of the watermark.

**[0012]** Ideally, a watermarking technique should embed detectible watermarks that resist modifications and attacks as long as they result in signals that are of perceptually the same quality. A watermarking technique that is resistant to modifications and attacks may be called "robust." Aspects of such techniques are called "robust" if they encourage such resistance.

**[0013]** Generally speaking, a watermarking system should be robust enough to handle unintentional noise introduction into the signal (such noise my be introduced by A/D and D/A conversions, compressions/decompressions, data corruption during transmission, etc.)

**[0014]** Furthermore, a watermarking system should be robust enough and stealthy enough to avoid purposeful and

malicious detection, alternation, and/or deletion of the watermark. Such an attack may use a "shotgun" approach where no specific watermark is known or detected (but is assumed to exist) or may use "sharp-shooter" approach where the specific watermark is attacked.

**[0015]** This robustness problem has attracted considerable attention. In general, the existing robust watermark techniques fall into two categories: spread-spectrum and quantization index modulation (QIM).

**[0016]** With the spread spectrum-type techniques, the watermark indexes the modification to the host data. The host data is the data of the original, unmarked digital signal (i.e., host signal). With typical spread-spectrum watermarking, each bit (e.g., 0s and 1s) of the watermark is embedded into the signal by slightly changing (e.g., adding a pseudorandom sequence that consists of $+\Delta$ or $+\Delta$) the signal.

**[0017]** With quantization index modulation (QIM), the watermark is embedded via indexing the modified host data. The modified host data is the data of the marked digital signal (i.e., marked host signal). This is discussed in more detail below.

**[0018]** Those of ordinary skill in the art are familiar with conventional techniques and technology associated with watermarks, watermark embedding, and watermark detecting. In addition, those of ordinary skill in the art are familiar with the typical problems associated with proper watermark detection after a marked signal has undergone changes (e.g., unintentional noise and malicious attacks).

## Desiderata of Watermarking Technology

**[0019]** Watermarking technology has several highly desirable goals (i.e., desiderata) to facilitate protection of copyrights of content publishers. Below are listed several of such goals.

### Perceptual Invisibility.

**[0020]** The embedded information should not induce perceptual changes in the signal quality of the resulting watermarked signal. The test of perceptual invisibility is often called the "golden eyes and ears" test.

### Statistical Invisibility.

**[0021]** The embedded information should be quantitatively imperceptive for any exhaustive, heuristic, or probabilistic attempt to detect or remove the watermark. The complexity of successfully launching such attacks should be well beyond the computation power of publicly available computer systems. Herein, statistical invisibility is expressly included within perceptual invisibility.

### Tamperproofness.

**[0022]** An attempt to remove the watermark should damage the value of the digital good well above the hearing threshold.

### Cost.

**[0023]** The system should be inexpensive to license and implement on both programmable and application-specific platforms.

### Non-disclosure of the Original.

**[0024]** The watermarking and detection protocols should be such that the process of proving digital good content copyright both in-situ and in-court, does not involve usage of the original recording.

### Enforceability and Flexibility.

**[0025]** The watermarking technique should provide strong and undeniable copyright proof. Similarly, it should enable a spectrum of protection levels, which correspond to variable digital good presentation and compression standards.

### Resilience to Common Attacks.

**[0026]** Public availability of powerful digital good editing tools imposes that the watermarking and detection process is resilient to attacks spawned from such consoles.

## False Alarms & Misses

**[0027]** When developing a watermarking technique, one does not want to increase the probability of a false alarm. That is when a watermark is detected, but none exists. This is something like finding evidence of a crime that did not happen. Someone may be falsely accused of wrongdoing.

**[0028]** As the probability of false alarms increases, the confidence in the watermarking technique decreases. For example, people often ignore car alarms because they know that more often than not it is a false alarm rather than an actual car theft.

**[0029]** Likewise, one does not want to increase the probability of a miss. This is when the watermark of a signal is not properly detected. This is something like overlooking key piece of evidence at a crime scene. Because of this, a wrongdoing may never be properly investigated. As the probability of misses increases, the confidence in the watermarking technique decreases.

**[0030]** Ideally, the probabilities of a false alarm and a miss are zero. In reality, a compromise is often made between them. Typically, a decrease in the probability of one increases the probability of the other. For example, as the probability of false alarm is decreased, the probability of a miss increases.

**[0031]** Consequently, a watermarking technique is needed that minimizes both while finding a proper balance between them.

## Quantization Index Modulation (QIM)

**[0032]** To that end some have proposed embedding a watermark by indexing the signal (e.g., host data) during the watermark embedding. This technique is called quantization index modulation (QIM) and it was briefly introduced above.

**[0033]** In general, quantization means to limit the possible values of (a magnitude or quantity) to a discrete set of values. Quantization may be thought of as a conversion from non-discrete (e.g., analog or continuous) values to discrete values. Alternatively it may be a conversion between discrete values with differing scales. Quantization may be accomplished mathematically through rounding or truncation. Typical QIM refers to embedding information by first modulating an index or sequence of indices with the embedded information and then quantizing the host signal with the associated quantizer or sequence of quantizers. A quantizer is class of discontinuous, approximate-identity functions.

**[0034]** The major proponent of such QIM techniques is Brian Chen and Gregory W. Wornell (i.e., Chen-Wornell). In their words, they have proposed, "dither modulation in which the embedded information modulates a dither signal and the host signal is quantized with an associated dither quantizer" (from Abstract of Chen-Wornell article from the *IEEE Trans. Inform. Theory*).

**[0035]** See the following documents for more details on Chen-Wornell's proposals and on QIM:

- B. Chen and G.W. Wornell, "Digital watermarking and information embedding using dither modulation," *Proc. IEEE Workshop on Multimedia Signal Processing*, Redondo Beach, CA, pp. 273-278, Dec. 1998;
- B. Chen and G. W. Wornell, "Dither modulation: a new approach to digital watermarking and information embedding," *Proc. of SPIE: Security and Watermarking of Multimedia Contents*, vol. 3657, pp. 342-353, 1999;
- B. Chen and G. W. Wornell, "Quantization Index Modulation: A class of Provably Good Methods for Digital Watermarking and Information Embedding," *IEEE Trans. Inform. Theory*, 1999 and 2000.

## Limitations of Conventional QIM

**[0036]** However, a key problem with conventional QIM is that it is susceptible to attacks and distortions. Conventional QIM relies upon local characteristics within relative to specific representation of a signal (e.g., in the time or frequency domain). To quantize, conventional QIM relies exclusively upon the values of "individual coefficients" of the representation of the signal. An example of such an "individual coefficients" is the color of an individual pixel of an image.

**[0037]** When quantizing, only the local characteristics of an "individual coefficient" are considered. These local characteristics may include value (e.g., color, amplitude) and relative positioning (e.g., positioning in time and/or frequency domains) of an individual bit (e.g., pixel).

**[0038]** Modifications—from either an attack or some type of unintentional noise— can change local characteristics of a signal quite dramatically. For example, these modifications may have a dramatic affect on the color of a pixel or the amplitude of a bit of sound. However, such modifications have little effect on non-local characteristics of a signal.

**[0039]** Accordingly, a new and robust watermarking technique is needed to findthe proper balance between minimizing the probability of false alarms and the probability of misses, such as QIM watermarking techniques. However, such a technique is needed that is less susceptible to attacks and distortions to the local characteristics within a signal.

## SUMMARY

[0040] Described herein is a technology for deriving robust non-local characteristics and quantizing such characteristics for blind watermarking of a digital good.

[0041] This technology finds the proper balance between minimizing the probability of false alarms (i.e., detecting a non-existent watermark) and the probability of misses (i.e., failing to detect an existing watermark). One possible technique is quantization index modulation (QIM) watermarking. However, conventional QIM is susceptible to attacks and distortions to the local characteristics of a digital good.

[0042] The technology, described herein, performs QIM based upon non-local characteristics of the digital good. Non-local characteristics may include statistics (e.g., averages, median) of a group of individual parts (e.g., pixels) of a digital good.

[0043] This summary itself is not intended to limit the scope of this patent. Moreover, the title of this patent is not intended to limit the scope of this patent. For a better understanding of the present invention, please see the following detailed description and appending claims, taken in conjunction with the accompanying drawings. The scope of the present invention is pointed out in the appending claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0044] The same numbers are used throughout the drawings to reference like elements and features.

[0045] Fig. 1 is a schematic block diagram showing a watermarking architecture in accordance with an implementation of the invention claimed herein.

[0046] Fig. 2 is a schematic block diagram showing an embodiment (e.g., a watermark embedding system) of the invention claimed herein.

[0047] Fig. 3 is a flow diagram showing an illustrative methodological implementation (e.g., watermark embedding) of the invention claimed herein.

[0048] Fig. 4 is a schematic block diagram showing an embodiment (e.g., a watermark detecting system) of the invention claimed herein.

[0049] Fig. 5 is a flow diagram showing an illustrative methodological implementation (e.g., watermark detecting) of the invention claimed herein.

[0050] Fig. 6 is an example of a computing operating environment capable of implementing an implementation (wholly or partially) of the invention claimed herein.

## DETAILED DESCRIPTION

[0051] In the following description, for purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific exemplary details. In other instances, well-known features are omitted or simplified to clarify the description of the exemplary implementations of present invention, thereby better explain the present invention. Furthermore, for ease of understanding, certain method steps are delineated as separate steps; however, these separately delineated steps should not be construed as necessarily order dependent in their performance.

[0052] The following description sets forth one or more exemplary implementations of a Derivation and Quantization of Robust Non-Local Characteristics for Blind Watermarking that incorporate elements recited in the appended claims. These implementations are described with specificity in order to meet statutory written description, enablement, and best-mode requirements. However, the description itself is not intended to limit the scope of this patent.

[0053] The inventors intend these exemplary implementations to be examples. The inventors do not intend these exemplary implementations to limit the scope of the claimed present invention. Rather, the inventors have contemplated that the claimed present invention might also be embodied and implemented in other ways, in conjunction with other present or future technologies.

[0054] An example of an embodiment of a Derivation and Quantization of Robust Non-Local Characteristics for Blind Watermarking may be referred to as "exemplary non-local QIM watermarker."

### Incorporation by Reference

[0055] The following co-pending patent applications are incorporated by reference herein (which are all assigned to the Microsoft Corportaion):

- U.S. Patent Application Serial No. 09/390271, entitled "A Technique for Watermarking an Image and a Resulting

Watermarked' Image" filed Sept. 7, 1999;

- U.S. Patent Application Serial No. 09/390272, entitled "A Technique for Detecting a Watermark in a Marked Image" filed on Sept. 7, 1999;
- U.S. Patent Application Serial No. 09/614,660, entitled "Improved Stealthy Audio Watermarking" filed on July 12,2000,; and
- U.S. Patent Application Serial No. 09/316,899, entitled "Audio Watermarking with Dual Watermarks" filed on May 22, 1999.

## Introduction

**[0056]** The one or more exemplary implementations, described herein, of the present claimed invention may be implemented (in whole or in part) by a non-local QIM watermarking architecture 100 and/or by a computing environment like that shown in Fig. 6.

**[0057]** In general, the exemplary non-local QIM watermarker derives robust non-local characteristics of a digital good. It quantizes such characteristics for blind watermarking of the digital good.

**[0058]** The exemplary non-local QIM watermarker minimizes the probability of false alarms (i.e., detecting a non-existent watermark) and the probability of misses (i.e., failing to detect an existing watermark). It does so by employing quantization index modulation (QIM) watermarking. However, it does not employ conventional QIM techniques because they are susceptible to attacks and distortions to the local characteristics of a digital good.

### Local Characteristics

**[0059]** Conventional QIM relies upon local characteristics within a signal (i.e., a digital good). To quantize, conventional QIM relies exclusively upon the values of "individual elements" of the host signal. When quantizing, only the local characteristics of an "individual element" are considered. These local characteristics may include value (e.g., color, amplitude) and relative positioning (e.g., positioning in time and/or frequency domains) of an individual bit (e.g., pixel).

**[0060]** Modifications—from either an attack or unintentional noise—can change local characteristics of a signal quite dramatically. For example, these modifications may have a dramatic affect on the color of a pixel or the amplitude of a bit of sound. However, such modifications have little effect on non-local characteristics of a signal.

### Non-Local Characteristics

**[0061]** Non-local characteristics are representative of general characteristics of a group or collection of individual elements. Such a group may be called a segment. Non-local characteristics are not representative of the individual local characteristics of the individual elements; rather, they are representative of the group (e.g., segments) as a whole.

**[0062]** The non-local characteristics may be determined by a mathematical or statistical representation of a group. For example, it may be an average of the color values of all pixels in a group. Consequently, such non-local characteristics may also be called "statistical characteristics." Local characteristics do not have statistical characteristics because a fixed value for a given category. Thus, no statistics are derived from a single value.

**[0063]** The non-local characteristics are not local characteristics. They are not global characteristics. Rather, they are in between. Consequently, they may also be called "semi-global" characteristics.

## Brief Overview

**[0064]** Given an original, unmarked good, the exemplary non-local QIM watermarker derives robust characteristics that are not local in nature. For example, the exemplary non-local QIM watermarker may employ randomized non-invertible transforms to produce robust non-local characteristics that can be modified without perceptual distortion. These characteristics are typically represented statistically and/or mathematically.

**[0065]** To embed the watermark, the exemplary non-local QIM watermarker performs quantization of these non-local characteristics in one or more dimensional lattices or vector spaces. The marked good that results from the exemplary non-local QIM watermarker is robust against unintentional and intentional modifications (e.g., malicious attacks). Examples of malicious attacks include de-synching, random bending, and many other benchmark attacks (e.g., Stirmark attacks).

## Exemplary Non-Local QIM Watermarking Architecture

**[0066]** **Fig. 1** shows a digital goods production and distribution architecture 100 (i.e., non-local QIM watermarking architecture 100) having a content producer/provider 122 that produces original content and distributes the content

over a network 124 to a client 126. The content producer/provider 122 has a content storage 130 to store digital goods containing original content. The content producer 122 has a watermark embedding system 132 to sign the digital signals with a watermark that uniquely identifies the content as original. The watermark embedding system 132 may be implemented as a standalone process or incorporated into other applications or an operating system.

**[0067]** The watermark embedding system 132 applies the watermark to a digital signal from the content storage 130. Typically, the watermark identifies the content producer 122, providing a signature that is embedded in the signal and cannot be cleanly removed.

**[0068]** The content producer/provider 122 has a distribution server 134 that distributes the watermarked content over the network 124 (e.g., the Internet). A signal with a watermark embedded therein represents to a recipient that the signal is being distributed in accordance with the copyright authority of the content producer/provider 122. The server 134 may further compress and/or encrypt the content conventional compression and encryption techniques prior to distributing the content over the network 124.

**[0069]** Typically, the client 126 is equipped with a processor 140, a memory 142, and one or more content output devices 144 (e.g., display, sound card, speakers, etc.). The processor 140 runs various tools to process the marked signal, such as tools to decompress the signal, decrypt the date, filter the content, and/or apply signal controls (tone, volume, etc.). The memory 142 stores an operating system 150 (such as a Microsoft® Windows 2000® operating system), which executes on the processor. The client 126 may be embodied in many different ways, including a computer, a handheld entertainment device, a set-top box, a television, an appliance, and so forth.

**[0070]** The operating system 150 implements a client-side watermark detecting system 152 to detect watermarks in the digital signal and a content loader 154 (e.g., multimedia player, audio player) to facilitate the use of content through the content output device(s) 144. If the watermark is present, the client can identify its copyright and other associated information.

**[0071]** The operating system 150 and/or processor 140 may be configured to enforce certain rules imposed by the content producer/provider (or copyright owner). For instance, the operating system and/or processor may be configured to reject fake or copied content that does not possess a valid watermark. In another example, the system could load unverified content with a reduced level of fidelity.

## Exemplary Non-Local QIM Watermark Embedding System

**[0072]** Fig. 2 shows an exemplary non-local QIM watermark embedding system 200, which is an example of an embodiment of a portion of the non-local QIM watermarking architecture 100. This system may be employed as the watermark encoding system 132 of Fig. 1.

**[0073]** The watermark embedding system 200 includes an amplitude normalizer 210, a transformer 220, a partitioner 230, segment-statistics calculator 240, a segment quantizer 250, a delta-sequence finder 260, and a signal marker 270.

**[0074]** The amplitude normalizer 210 obtains a digital signal 205 (such as an audio clip). It may obtain the signal from nearly any source, such as a storage device or over a network communications link. As its name implies, it normalizes the amplitude of the signal.

**[0075]** The transformer 220 receives the amplitude-normalized signal from the normalizer 210. The transformer 220 puts the signal in canonical form using a set of transformations. Specifically, discrete wavelet transformation (DWT) may be employed (particularly, when the input is an image) since it compactly captures significant signal characteristics via time and frequency localization. Other transformations may be used. For instance, shift-invariant and shape-preserving "complex wavelets" and any overcomplete wavelet representation or wavelet packet are good candidates (particularly for images).

**[0076]** The transformer 220 also finds the DC subband of the initial transformation of the signal. This DC subband of the transformed signal is passed to the partitioner 230.

**[0077]** The partitioner 230 separates the transformed signal into multiple, pseudorandomly sized, pseudorandomly positioned, adjacent, non-contiguous segments (i.e., partitions). A secret key $K$ is the seed for pseudorandom number generation here. This same $K$ may be used to reconstruct the segments by an exemplary non-local QIM watermark detecting system 400.

**[0078]** For example, if the signal is an image, it might be partitioned into two-dimensional polygons (e.g., rectangles) of pseudorandom size and location. In another example, if the signal is an audio clip, a two-dimensional representation (using frequency and time) of the audio clip might be separated into two-dimensional polygons (e.g., triangles) of pseudorandom size and location.

**[0079]** In this implementation, the segments do not overlap. They are adjacent and non-contiguous. In alternative implementations, the segments may be overlapping.

**[0080]** For each segment, the segment-statistics calculator 240 calculates statistics of the multiple segments generated by the partitioner 230. Statistics for each segment are calculated. These statistics may be, for example, any finite order moments of a segment. Examples of such include the mean, the median, and the standard deviation.

**[0081]** Generally, the statistics calculations for each segment are independent of the calculations of other segments. However, other alternatives may involve calculations dependent on data from multiple segments.

**[0082]** A suitable statistic for such calculation is the mean (e.g., average) of the values of the individual bits of the segment. Other suitable statistics and their robustness are discussed in Venkatesan, Koon, Jakubowski, and Moulin, "Robust image hashing," *Proc. IEEE ICIP 2000,* Vancouver, Canada, September 2000. In this document, no information embedding was considered, but similar statistics were discussed.

**[0083]** For each segment, the segment quantizer 250 applies a multi-level (e.g., 2, 3, 4) quantization (i.e., high-dimensional, vector-dimensional, or lattice-dimensional quantization) on the output of the segment-statistics calculator 240 to obtain quantitized data. Of course, other levels of quantization may be employed. The quantizer 250 may be adaptive or non-adaptive.

**[0084]** This quantization may be done randomly also. This may be called randomized quantization (or randomized rounding). This means that the quantizer may randomly decide to round up or round down. It may do it pseudorandomly (using the secret key). This adds an additional degree of robustness and helps hide the watermark.

**[0085]** The delta-sequence finder 260 finds a pseudorandom sequence $Z$ that estimates the difference (i.e., delta) between the original transformed signal $X$ and the combination of segments of quantized statistics. The pseudorandom sequence $Z$ may also be called the delta-sequence. For example, if the statistic is averaging, then $Z$ s.t. $\text{Avg}_i(X+Z) = \text{Avg}_i(\hat{X}) = \hat{\mu}_i$, where $\hat{X}$ is the marked signal and $\hat{\mu}_i$ is average for a segment.

**[0086]** When finding a delta-sequence $Z$, it is desirable to minimize the perceptual distortion; therefore, some perceptual distortion metrics may be employed to create this sequence. Thus, in creating $Z$ for, the criteria may include a combination of that minimizes the visual distortions on $X+Z$ (compared to $\hat{X}$) and minimizes the distance between the statistics of $X+Z$ and quantized statistics of $X$.

**[0087]** The signal marker 270 marks the signal with delta-sequence $Z$ so that $\hat{X} = X+Z$. The signal marker may mark the signal using QIM techniques. This marked signal may be publicly distributed to consumers and clients.

**[0088]** The functions of aforementioned components of the exemplary non-local QIM watermark embedding system 200 of Fig. 2 are explained in more detail below.

## Methodological Implementation of the Exemplary Non-Local QIM Watermark Embedding

**[0089]** **Fig. 3** shows the methodological implementation of the exemplary non-local QIM watermark embedding system 200 (or some portion thereof). More specifically, this figure shows the methodological implementation of watermark embedding of the exemplary non-local QIM watermarker. This methodological implementation may be performed in software, hardware, or a combination thereof.

**[0090]** At 310 of Fig. 3, the exemplary non-local QIM watermarker normalizes the amplitude of the input. The input is the original, unmarked signal (i.e., digital good). At 312, it finds a transform of the amplitude-normalized signal and gets the lowest frequency band (e.g., the DC subband). The result of this block is a transformed signal. This transformation is a discrete wavelet transformation (DWT), but most any other similar transformation may be performed in alternative implementations.

**[0091]** At 314, the exemplary non-local QIM watermarker partitions the transformed signal into multiple, pseudorandomly sized, pseudorandomly positioned, adjacent, non-contiguous segments. A secret key $K$ is the seed for pseudorandom number generation here. This same $K$ may be used to reconstruct the segments in the watermark detecting process.

**[0092]** For example, if the signal is an image, it might be separated into two-dimensional polygons (e.g., rectangles) of pseudorandom size and location. In another example, if the signal is an audio clip, a two-dimensional representation (using frequency and time) of the audio clip might be separated into two-dimensional polygons (e.g., trapezoids) of pseudorandom size and location.

**[0093]** In this implementation, the segments do not overlap. They are adjacent and non-contiguous. In alternative implementations, the segments may be overlapping.

**[0094]** For each segment of the signal, the exemplary non-local QIM watermarker repeats blocks 320 through 330. Thus, each segment is processed in the same manner.

**[0095]** At 322 of Fig. 3, the exemplary non-local QIM watermarker has a watermark (or a portion thereof) to embed in the current segment. It finds quantized values of statistics of the segment (e.g., averages within the segment or as close as possible). At this point, scalar uniform quantizer and reconstruction points may be randomly perturbed with $K$ as the seed.

**[0096]** At 324, the exemplary non-local QIM watermarker finds a pseudorandom sequence $Z$ where the statistics calculation (e.g., averaging) of this sequence combined with the segmented signal generates the calculation of watermarked signal segment. This is also equal to the quanitized statistics of the signal segment.

**[0097]** At 330, the process loops back to 320 for each unprocessed segment. If all segments have been processed, then it proceeds to 340.

**[0098]** At 340 of Fig. 3, the exemplary non-local QIM watermarker combines the pseudorandom sequence with the signal segments to get the watermarked signal segments. In addition, the watermarked signal segments are combined to form a full watermarked signal. In other words, $\hat{X} = X + Z$. At 350, the process ends.

## Exemplary Non-Local QIM Watermark Detecting System

**[0099]** **Fig. 4** shows an exemplary non-local QIM watermark detecting system 400, which is an example of an embodiment of a portion of the non-local QIM watermarking architecture 100. This system may be employed as the watermark detecting system 152 of Fig. 1.

**[0100]** The watermark detecting system 400 includes an amplitude normalizer 410, a transformer 420, a partitioner 430, segment-statistics calculator 440, a segment MAP decoder 450, a watermark-presence determiner 460, a presenter 470, and a display 480.

**[0101]** The amplitude normalizer 410, the transformer 420, the partitioner 430, and the segment-statistics calculator 440 of the watermark detecting system 400 of Fig. 4 function in a similar manner as similarly labeled components of the watermark embedding system 200 of Fig. 2. The exception is that the object of these components is a "subject signal" rather than the original signal. A "subject signal" signal is an unknown. It may or may not include a watermark. It may have been modified.

**[0102]** For each segment, the segment MAP decoder 450 determines a quantized value using the MAP decoding scheme. In general, MAP techniques involve finding (and possibly ranking by distance) all objects (in this instance, quantized values) in terms of their distance from a "point." In this example, the "point" is the statistics calculated for a given segment. Nearest-neighbor decoding is one specific instance of MAP decoding. Those of ordinary skill in the art understand and appreciate MAP and nearest-neighbor techniques.

**[0103]** In addition, the segment MAP decoder 450 determines a confidence factor based upon the distance between the quanitized values and the statistics calculated for a given segment. If they are coexistent, then factor will indicate a high degree of confidence. If they are distant, then it may indicate a low degree of confidence. Furthermore, the decoder 450 combines the confidence factors of the segments to get an overall confidence factor. That combination may be most any statistical combination (e.g., addition, average, median, standard deviation, etc.).

**[0104]** The watermark-presence determiner 460 determines whether a watermark is present. The determiner may use some distortion metric $d(w, \hat{w})$ and some threshold T to decide if watermark is present or not. A normalized Hamming distance may be used.

**[0105]** The presenter 470 presents one of three indications: "watermark present," "watermark not present," and "unknown." If the confidence factor is low, it may indicate "unknown." In addition, it may present the confidence-indication value.

**[0106]** This information is presented on the display 480. Of course, this display may be any output device. It may also be a storage device.

**[0107]** The functions of aforementioned components of the exemplary non-local QIM watermark detecting system 400 of Fig. 4 are explained in more detail below.

## Methodological Implementation of the Exemplary Non-Local QIM Watermark Detecting

**[0108]** **Fig. 5** shows the methodological implementation of the exemplary non-local QIM watermark detecting system 400 (or some portion thereof). More specifically, this figure shows the methodological implementation of watermark detecting of the exemplary non-local QIM watermarker. This methodological implementation may be performed in software, hardware, or a combination thereof.

**[0109]** At 510 of Fig. 5, the exemplary non-local QIM watermarker normalizes the amplitude of the input. The input is an unknown specimen (i.e., signal) of a digital good. It is not known whether this signal includes a watermark or not.

**[0110]** At 512, it finds a transform of the amplitude-normalized signal and gets significant frequency subband. That may be a low or the lowest subband (e.g., the DC subband). Generally, the subband selected may be one that represents the signal is a manner that helps further robust watermarking and detection of the watermark. The lower frequency subbands are suitable because they tend to remain relatively invariant after signal perturbation.

**[0111]** The result of this block is a transformed signal. When watermarking an image, an example of a suitable transformation is discrete wavelet transformation (DWT). When watermarking an audio clip, an example of a suitable transformation is MCLT (Modulated Complex Lapped Transform). However, most any other similar transformation may be performed in alternative implementations.

**[0112]** At 514, the exemplary non-local QIM watermarker partitions the transformed signal into multiple, pseudorandomly sized, pseudorandomly positioned, adjacent, non-contiguous segments. It uses the same secret key K is the seed for its pseudorandom number generation here. Therefore, this process generates the same segments as in the embedding process.

**[0113]** For each segment of the signal, the exemplary non-local QIM watermarker repeats blocks 520 through 530. Thus, each segment is processed in the same manner.

**[0114]** At 522 of Fig. 5, the exemplary non-local QIM watermarker finds statistics of the segment (e.g., averages within the segment). At 524, the exemplary non-local QIM watermarker finds decoded watermark (or a portion thereof) using Maximum A Posteriori (MAP) decoding. An example of such a MAP decoding is nearest-neighbor decoding.

**[0115]** At 526, it measures how close each decoded value is to a quanitized value and tracks such measurements. The data provided by such measurements may provide an indication of the confidence of a resulting watermark-presence determination.

**[0116]** At 530, the process loops back to 520 for each unprocessed segment. If all segments have been processed, then it proceeds to 540.

**[0117]** At 540 of Fig. 5, the exemplary non-local QIM watermarker determines whether a watermark is present. At 542, it determines a confidence-indication, which is based upon the tracked measurement data.

**[0118]** At 544, based upon the watermark-presence determination of block 540 and the confidence-indication of block 544, the exemplary non-local QIM watermarker provides one of three indications: watermark present, watermark not present, and unknown. In addition, it may present the confidence-indication value.

**[0119]** At 550, the process ends.

## Probability of False Alarms and Misses

**[0120]** There is a relationship between Probability of false alarm ($P_F$), Probability of miss ($P_M$), and the average sizes of the segments. $P_F$ is the probability of declaring that a watermark is present even though it is not. $P_M$ is the probability declaring that a watermark is not present although it is present indeed. Generally, the average segment size is relatively *directly* proportional to the $P_F$, but it is relatively *indirectly* proportional to the $P_M$.

**[0121]** For example, if the average segment-size is extremely small. So small that they are equivalent to the individual bits (e.g., equal to a pixel in an image. In that situation, watermarks are embedded in single coefficients, which is equivalent to the conventional schemes based on local characteristics. For such a case, $P_F$ is very small and $P_M$ is high. Conversely, if the average segment-size is extremely large. So large that it is the maximum size of the signal (e.g., the whole image). In that situation, $P_M$ is presumably very low whereas $P_F$ is high.

## Other Implementation Details

**[0122]** For the following descriptions of an implementation of the exemplary non-local QIM watermarker, assume the following:

**[0123]** The input signal $\underline{X}$ is an image. Of course, for signal may be other types for other implementations. However, for this example implementation, the signal is an image. Let $\underline{w}$ be the watermark (a binary vector) to be embedded in $\underline{X}$ and a random binary string $K$ be the secret key. The output of a watermark encoder, $\hat{\underline{X}}$ is the watermarked image in which the information $\underline{w}$ is hidden via the secret key $K$. This image will possibly undergo various attacks, yielding $\tilde{\underline{X}}$. A watermark decoder, given $\tilde{\underline{X}}$ and the secret key $K$ outputs $\hat{\underline{w}}$. It is required that $\hat{\underline{X}}$ and $\underline{X}$ are approximately the same for all practical purposes and that $\hat{\underline{X}}$ is still of acceptable quality. The decoder uses some distortion metric $d(\underline{w}, \hat{\underline{w}})$ and some threshold $T$ to decide if watermark is present or not. The exemplary non-local QIM watermarker use a normalized Hamming distance, which is the ratio of the usual Hamming distance and the length of the inputs.

### WM via Quantization

**[0124]** The exemplary non-local QIM watermarker computes a vector $\underline{\mu}$ by applying a forward transformation $T_F$ on $\underline{X}$. The exemplary non-local QIM watermarker assumes that $\underline{X}$ is a grayscale image; if not, a linear transformation may be applied on a colored image to obtain the intensity image. (For colored images, most of the energy is concentrated in the intensity plane). Once the information hiding process is done via quantization, there is $\hat{\underline{\mu}}$, and the watermarked $\hat{\underline{X}}$ data are obtained by applying the transform $T_R$ on $\hat{\underline{\mu}}$. The exemplary non-local QIM watermarker randomizes the process using a random string derived from our secret key $K$ as a seed to a pseudo-random generator.

**[0125]** The scheme is generic. So most any transform may be used. In addition, $T_F = (T_R)^{-1}$ need not be true, or even that their inverses exist. The exemplary non-local QIM watermarker does not constrain the space where quantization occurs. The decoder applys the transform $T_F$ on the input, $\underline{Y}$, to get the output is $\underline{\mu}_Y$ and applying approximate Maximum Likelihood (ML) estimation of the possibly embedded sequence $\hat{\underline{w}}_Y$. Through a pseudo-random generator, $K$ will determine many randomization functions of the transform, quantization and estimation stages $\hat{\underline{w}}_Y$. Once is found, it is compared with the embedded watermark $\underline{w}$, if the distance between them is close to 0 (or less than a threshold $T$), then it is declared that the watermark is present; otherwise not present. This contrasts with the natural measure for spread spectrum techniques that yields a high value of correlation if the watermark is present.

More Details of this Methodological Implementation

**[0126]** The transforms $T_F$ and $T_R$ help enhance robustness. For $T_F$ to retain significant image characteristics, we may use discrete wavelet transformation (DWT) at the initial stage. Next, semi-global (i.e., non-local) statistics of segments are determined of the image. The local statistics are not robust.

**[0127]** When the exemplary non-local QIM watermarker computes, for example, the first order statistics of an original image signal and computes several attacked versions for *random* rectangles of fixed size. Then the average mean squared error between these statistics may be found. The error monotonically decays as the size of therectangles is increased.

**[0128]** In $T_F$ $\underline{\mu}$ is set to be the estimated first order statistics of randomly chosen rectangles in the wavelet domain. Here $T_F$ is not invertible if the number of rectangles is less than the number of coefficients. To choose $T_R$, one might first generate a pseudo-random sequence $\underline{\rho}$ in the image domain that has the property to be visually approximately unnoticeable. pass it through $T_F$ find the corresponding statistics $\underline{\mu}_\rho$, compute the necessary scaling factors $\underline{\alpha}$ such that the pseudorandom sequence $\underline{\rho}$ scaled by $\underline{\alpha}$ and added to $\underline{X}$ yields the averages $\hat{\underline{\mu}}$ that is quantized $\underline{\mu}$. This implementation uses randomly chosen non-overlapping rectangles. The exemplary non-local QIM watermarker defines two quantizers, $Q_0$ and $Q_1$ which map vectors in $R^n$ to some nearby chosen lattice points.

**[0129]** Here is a formal description. Define $Q_i = \{(q_{ij}, S_{ij}) | j \in Z\}$; $q_{ij} \in R^n$ to be *reconstruction points* for $Q_i$; $S_{ij} \subset$ are the corresponding *quantization bins*; $i \in \{0,1\}$ . $j \in Z$ . For each $j$, then $S_{0j} \cap [(\cup_{k \neq j} S_{0k}) \cup (\cap_k S_{1k})] = S_{1j} \cap [(\cup_{k \neq j} S_{1k}) \cup (\cup_k S_{0k})] = \emptyset$. Here $q_{0j}, q_{1j}$ are determined in a pseudo-random fashion (using $K$ as the seed of the random number generator) and $n$ is the dimension of quantization. The exemplary non-local QIM watermarker defines $Q_0[a] = q_{0j} \Leftrightarrow a \in S_{0j}$, and likewise for $Q_1$. Both $Q_0$ and $Q_1$ are derived from a single quantizer, $Q$, such that *(a)* the set of reconstruction points of $Q$ is equal to $\{q_{0j}\}_j \cup \{q_{1j}\}_j$ and *(b)* for all $j,k$, $\min_{i \in Z} d_{L2}[E(q_{0j}), E(q_{1i})] = \min_{i \in Z} d_{L2}[E(q_{0i}), E(q_{1k})]$. Let $\xi$ denote the common value *(c)* for each fixed $k$. $\phi_k := \min_{j \neq k} d_{L2}[E(q_{0j}), E(q_{0k})] = \min_{j \neq k} d_{L2}[E(q_{1j}), E(q_{1k})]$ and $\phi_i = \phi_j > \xi$ for all $i,j$. Here $d_{L2}$ is the $L_2$ distortion metric. and $E(.)$ is the expectation operator over the pseudo-random choices $q_{ij}$.

**[0130]** If, for example, $n=1$. The exemplary non-local QIM watermarker finds $\{E(q_{0j})\}$ and $\{E(q_{1j})\}$ meeting the requirements mentioned above Then *randomization regions* that are neighborhoods in $R^n$ around $\{E(q_{0j})\}$ and $\{E(q_{1j})\}$ are introduced. Then $\{q_{0j}\}$ and $\{q_{1j}\}$ are randomly choosen from these regions using some suitable probability distributions. The sizes of the randomizing regions and their shapes are input parameters. Let $nR$ be the number of rectangles each indexed suitably. Let $R$ be the length of the binary watermark vector $\underline{w}$ to be hidden in rectangles. For a vector, $\underline{v}$ denotes its $i$-th entry by $\underline{v}(i)$. Let $L$ denote the number of levels of DWT that is applied.

Encoding

**[0131]** Let $N$ be the number of pixels in $\underline{X}$ and $\underline{s} := [s_1, \ldots, s_N]$ be the vector that consists of pixels of $\underline{X}$ sorted in ascending order. Create subvectors $\underline{s}_L := [s_t, \ldots, s_t]$ where $t = round(N(1-\beta)\gamma)$ and $t' = round(N(1+\beta)\gamma)$ and $\underline{s}_H := [s_u, s_{u'}]$ where $u = round(N[1-(1-\beta)\gamma])$and $u' = round(N[(1+\beta)\gamma])$. Here $round(r)$ equals the nearest integer to $r$ and the system parameters $0<\beta, \gamma<<1$. Let $m$ and $M$ be the mean values of the elements of $\underline{s}_L$ and $\underline{s}_H$ respectively. Apply the point operator $P[\chi] = 255 * (\chi - m)/(M-m)$ to each element of $\underline{X}$ to get $\underline{X}'$

**[0132]** Find the $L$-level DWT $\underline{X}'$. Let $\underline{X}_A$ be its DC subband.

**[0133]** Partition the $\underline{X}_A$ into random non overlapping $nR$ rectangles; calculate $\underline{\mu}$ such that $\underline{\mu}(i)$ is the mean value of the coefficients within rectangle $i$, $i \leq nR$.

**[0134]** Let $\underline{\mu}^i := [\underline{\mu}(n(i-1)+1), \ldots, \underline{\mu}(ni-1), \underline{\mu}(ni)], i \leq R$. Use $Q_0$ and $Q_1$ to quantize: for $i \leq R$, if $\underline{w}(i) = 0$, quantize $\underline{\mu}^i$ using $Q_0$ else quantize $\underline{\mu}^i$ using $Q_1$. Concatenating the quantized $\{\underline{\mu}^i\}$ we get $\hat{\underline{\mu}}$.

**[0135]** Find the differences between the original statistics and the quantized statistics: $\underline{d} = \hat{\underline{\mu}} - \underline{\mu}$.

**[0136]** Generate a pseudo-random sequence $\underline{\rho} = [\rho_{ij}]$ in the spatial (i.e. the original image) domain as follows: Choose $\rho_{ij}$ randomly and uniformly from $\{0,1\}$ if $s_t < X_{ij} < s_{t'}$, where $t' = round(N\gamma)$ and $t = round(N(1-\gamma))$; otherwise set $\rho_{ij} = 0$. Now apply $L$-level DWT to the matrix $\underline{\rho}$, extract the DC subband of the output and call it $\underline{\rho}_W$ . Now compute the corresponding statistics similar to the step

**[0137]** Compute the scaling factors $\underline{\alpha}$ such that $\underline{\alpha}(i) = \underline{d}(i)/\underline{\mu}_\rho(i), i \leq nR$.

**[0138]** For each rectangle whose index is $i$, multiply all coefficients of $\underline{\rho}_W$ within that rectangle by $\underline{\alpha}(i)$, let the resulting vector be $\hat{\underline{\rho}}_W$.

**[0139]** Apply inverse DWT on $\hat{\underline{\rho}}_W$ ,let the output be $\hat{\rho}$.

**[0140]** Compute the watermarked data: $\underline{X}'' = \underline{X}' + \hat{\underline{\rho}}$. Apply the inverse of the point operator (see step 1) on $\underline{X}''$ to get $\hat{\underline{X}}$.

Decoding (input $\underline{Y}$):

**[0141]** Similar to first part of the encoding above, find the corresponding point operator on $\underline{Y}$. Now apply the operator to $\underline{Y}$ and to the output apply $L$-level DWT, extract the DC subband and call it $\underline{Y}_A$.

[0142] Applying the partitioning procedure of the encoding above to $\underline{Y}$ and find its statistics $\underline{\mu}_Y$. Let $\underline{\mu}_Y(i)$ be the $i$th element.

[0143] Using $Q_0$ and $Q_1$, now is described how to carry out approximate ML estimation to find the decoded sequence $\underline{w}_Y$: Let

$$\underline{\mu}_Y^i := \left[\underline{\mu}_Y(n(i-1)+1), \ldots, \underline{\mu}_Y(ni-1), \underline{\mu}_Y(ni)\right]$$

[0144] For rectangles indexed by $n(i-1)+1,\ldots,ni-1,ni$, $i \leq R$, let $r0(i)$ be the closest point to $\underline{\mu}_Y^i$ among reconstruction points of $Q_0$; likewise let $r1(i)$ be the closest point to $\underline{\mu}_Y^i$ among reconstruction points of $Q_1$. If

$$d_{l2}\left(\underline{\mu}_Y^i, r0(i)\right) < d_{l2}\left(\underline{\mu}_Y^i, r1(i)\right)$$

then assign $\underline{w}_Y(i)=0$; otherwise $\underline{w}_Y(i)=1$.

[0145] Compute $d(\underline{w}_Y, \underline{w})$. If the result is *less* than threshold $T$, declare that the watermark was detected, or otherwise not present.

## Exemplary Computing System and Environment

[0146] Fig. 6 illustrates an example of a suitable computing environment 900 within which an exemplary non-local QIM watermarker, as described herein, may be implemented (either fully or partially). The computing environment 900 may be utilized in the computer and network architectures described herein.

[0147] The exemplary computing environment 900 is only one example of a computing environment and is not intended to suggest any limitation as to the scope of use or functionality of the computer and network architectures. Neither should the computing environment 900 be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary computing environment 900.

[0148] The exemplary non-local QIM watermarker may be implemented with numerous other general purpose or special purpose computing system environments or configurations. Examples of well known computing systems, environments, and/or configurations that may be suitable for use include, but are not limited to, personal computers, server computers, thin clients, thick clients, hand-held or laptop devices, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, and the like.

[0149] The exemplary non-local QIM watermarker may be described in the general context of computer-executable instructions, such as program modules, being executed by a computer. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. The exemplary non-local QIM watermarker may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote computer storage media including memory storage devices.

[0150] The computing environment 900 includes a general-purpose computing device in the form of a computer 902. The components of computer 902 can include, by are not limited to, one or more processors or processing units 904, a system memory 906, and a system bus 908 that couples various system components including the processor 904 to the system memory 906.

[0151] The system bus 908 represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, such architectures can include an Industry Standard Architecture (ISA) bus, a Micro Channel Architecture (MCA) bus, an Enhanced ISA (EISA) bus, a Video Electronics Standards Association (VESA) local bus, and a Peripheral Component Interconnects (PCI) bus also known as a Mezzanine bus.

[0152] Computer 902 typically includes a variety of computer readable media. Such media can be any available media that is accessible by computer 902 and includes both volatile and non-volatile media, removable and non-removable media.

[0153] The system memory 906 includes computer readable media in the form of volatile memory, such as random access memory (RAM) 910, and/or non-volatile memory, such as read only memory (ROM) 912. A basic input/output system (BIOS) 914, containing the basic routines that help to transfer information between elements within computer 902, such as during start-up, is stored in ROM 912. RAM 910 typically contains data and/or program modules that are

immediately accessible to and/or presently operated on by the processing unit 904.

**[0154]** Computer 902 may also include other removable/non-removable, volatile/non-volatile computer storage media. By way of example, Fig. 6 illustrates a hard disk drive 916 for reading from and writing to a non-removable, non-volatile magnetic media (not shown), a magnetic disk drive 918 for reading from and writing to a removable, non-volatile magnetic disk 920 (e.g., a "floppy disk"), and an optical disk drive 922 for reading from and/or writing to a removable, non-volatile optical disk 924 such as a CD-ROM, DVD-ROM, or other optical media. The hard disk drive 916, magnetic disk drive 918, and optical disk drive 922 are each connected to the system bus 908 by one or more data media interfaces 926. Alternatively, the hard disk drive 916, magnetic disk drive 918, and optical disk drive 922 can be connected to the system bus 908 by one or more interfaces (not shown).

**[0155]** The disk drives and their associated computer-readable media provide non-volatile storage of computer readable instructions, data structures, program modules, and other data for computer 902. Although the example illustrates a hard disk 916, a removable magnetic disk 920, and a removable optical disk 924, it is to be appreciated that other types of computer readable media which can store data that is accessible by a computer, such as magnetic cassettes or other magnetic storage devices, flash memory cards, CD-ROM, digital versatile disks (DVD) or other optical storage, random access memories (RAM), read only memories (ROM), electrically erasable programmable read-only memory (EEPROM), and the like, can also be utilized to implement the exemplary computing system and environment.

**[0156]** Any number of program modules can be stored on the hard disk 916, magnetic disk 920, optical disk 924, ROM 912, and/or RAM 910, including by way of example, an operating system 926, one or more application programs 928, other program modules 930, and program data 932. Each of such operating system 926, one or more application programs 928, other program modules 930, and program data 932 (or some combination thereof) may include an embodiment of an amplitude normalizer, a transformer, a partitioner, a segment-statistics calculator, a segment quantizer, an delta-sequence finder, and a signal marker.

**[0157]** A user can enter commands and information into computer 902 via input devices such as a keyboard 934 and a pointing device 936 (e.g., a "mouse"). Other input devices 938 (not shown specifically) may include a microphone, joystick, game pad, satellite dish, serial port, scanner, and/or the like. These and other input devices are connected to the processing unit 904 via input/output interfaces 940 that are coupled to the system bus 908, but may be connected by other interface and bus structures, such as a parallel port, game port, or a universal serial bus (USB).

**[0158]** A monitor 942 or other type of display device can also be connected to the system bus 908 via an interface, such as a video adapter 944. In addition to the monitor 942, other output peripheral devices can include components such as speakers (not shown) and a printer 946 which can be connected to computer 902 via the input/output interfaces 940.

**[0159]** Computer 902 can operate in a networked environment using logical connections to one or more remote computers, such as a remote computing device 948. By way of example, the remote computing device 948 can be a personal computer, portable computer, a server, a router, a network computer, a peer device or other common network node, and the like. The remote computing device 948 is illustrated as a portable computer that can include many or all of the elements and features described herein relative to computer 902.

**[0160]** Logical connections between computer 902 and the remote computer 948 are depicted as a local area network (LAN) 950 and a general wide area network (WAN) 952. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets, and the Internet.

**[0161]** When implemented in a LAN networking environment, the computer 902 is connected to a local network 950 via a network interface or adapter 954. When implemented in a WAN networking environment, the computer 902 typically includes a modem 956 or other means for establishing communications over the wide network 952. The modem 956, which can be internal or external to computer 902, can be connected to the system bus 908 via the input/output interfaces 940 or other appropriate mechanisms. It is to be appreciated that the illustrated network connections are exemplary and that other means of establishing communication link(s) between the computers 902 and 948 can be employed.

**[0162]** In a networked environment, such as that illustrated with computing environment 900, program modules depicted relative to the computer 902, or portions thereof, may be stored in a remote memory storage device. By way of example, remote application programs 958 reside on a memory device of remote computer 948. For purposes of illustration, application programs and other executable program components such as the operating system are illustrated herein as discrete blocks, although it is recognized that such programs and components reside at various times in different storage components of the computing device 902, and are executed by the data processor(s) of the computer.

### Computer-Executable Instructions

**[0163]** An implementation of an exemplary non-local QIM watermarker may be described in the general context of computer-executable instructions, such as program modules, executed by one or more computers or other devices.

Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Typically, the functionality of the program modules may be combined or distributed as desired in various embodiments.

## Exemplary Operating Environment

**[0164]** Fig. 6 illustrates an example of a suitable operating environment 900 in which an exemplary non-local QIM watermarker may be implemented. Specifically, the exemplary non-local QIM watermarker(s) described herein may be implemented (wholly or in part) by any program modules 928-930 and/or operating system 926 in Fig. 6 or a portion thereof.

**[0165]** The operating environment is only an example of a suitable operating environment and is not intended to suggest any limitation as to the scope or use of functionality of the exemplary non-local QIM watermarker(s) described herein. Other well known computing systems, environments, and/or configurations that are suitable for use include, but are not limited to personal computers (PCs), server computers, hand-held or laptop devices, multiprocessor systems, microprocessor-based systems, programmable consumer electronics, wireless phones and equipments, general- and special-purpose appliances, application-specific integrated circuits (ASICs), network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, and the like.

## Computer Readable Media

**[0166]** An implementation of an exemplary non-local QIM watermarker may be stored on or transmitted across some form of computer readable media. Computer readable media can be any available media that can be accessed by a computer. By way of example, and not limitation, computer readable media may comprise "computer storage media" and "communications media."

**[0167]** "Computer storage media" include volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules, or other data. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology. CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computer.

**[0168]** "Communication media" typically embodies computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as carrier wave or other transport mechanism. Communication media also includes any information delivery media.

**[0169]** The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared, and other wireless media. Combinations of any of the above are also included within the scope of computer readable media.

## Conclusion

**[0170]** Although the invention has been described in language specific to structural features and/or methodological steps, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or steps described. Rather, the specific features and steps are disclosed as preferred forms of implementing the claimed invention.

## Claims

1. A method facilitating protection of digital signals, the method comprising:

   normalizing amplitude of a digital signal, wherein such signal is an original, unmarked signal;
   transforming the normalized signal;
   partitioning the normalized signal transform into segments;
   for one or more segments:

   - calculating statistics of a segment that are representative of that segment;

- quantizing such statistics of a segment;

generating a delta-sequence representing a combination of the quantized statistics of the one or more segments or an approximation of the combination;
marking the digital signal with the delta-sequence.

2. A method as recited in claim 1, wherein the partitioning comprises pseudorandomly segmenting the normalized signal transform.

3. A method as recited in claim 1, wherein the partitioning comprises pseudorandomly segmenting the normalized signal transform, wherein such segments are adjacent and non-contiguous.

4. A method as recited in claim 1, wherein the transforming comprises finding a low frequency subband.

5. A method as recited in claim 1, wherein the transforming comprises finding a significant frequency subband.

6. A method as recited in claim 1, wherein the statistics of the calculating comprises one or more finite order moments of a segment.

7. A method as recited in claim 1, wherein the generating comprises producing a pseudorandom delta-sequence that when combined with the digital signal approximate a combination of the digital signal and the quantized statistics of the one or more segments.

8. A method as recited in claim 1, wherein the marking comprises embedding a watermark via quantization index modulation (QIM).

9. A modulated signal generated in accordance with the acts recited in claim 1.

10. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 1.

11. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 1.

12. A method facilitating protection of digital signals, the method comprising:

normalizing amplitude of a subject digital signal;
transforming the normalized signal;
partitioning the normalized signal transform into segments;
for one or more segments:

- calculating statistics of a segment that are representative of that segment;
- quantizing such statistics of a segment to generated a quantized value of that segment;
- measuring the distance between such statistics of a segment and the quantized value of that segment;

determining whether a watermark is present in the digital signal based upon the quantized values of the one or more segments.

13. A method as recited in claim 12, wherein measuring the distance comprising using perceptual distortion matrics.

14. A method as recited in claim 12 further comprising:

determining an indication of confidence based upon the measured distances of the measuring;
indicating an indication of confidence.

15. A method as recited in claim 12 further comprising indicating whether a watermark is present.

16. A method as recited in claim 12 further comprising indicating whether a watermark is present, wherein such indi-

cation is selected from a group consisting of "present," "not present," and "unknown."

17. A method as recited in claim 12, wherein the partitioning comprises pseudorandomly segmenting the normalized signal transform.

18. A method as recited in claim 12, wherein the partitioning comprises pseudorandomly segmenting the normalized signal transform, wherein such segments are adjacent and non-contiguous.

19. A method as recited in claim 12, wherein the transforming comprises finding a low frequency subband.

20. A method as recited in claim 12, wherein the transforming comprises finding a significant frequency subband.

21. A method as recited in claim 12, wherein the statistics of the calculating comprises one or more finite order moments of a segment.

22. A method as recited in claim 12, wherein the determining comprises detecting a watermark via quantization index modulation (QIM) techniques.

23. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 12.

24. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 12.

25. A method facilitating protection of digital signals, the method comprising:

partitioning a digital signal into segments;
for one or more segments:

- calculating statistics of a segment that are representative of that segment;
- quantizing such statistics of a segment;

generating a marked signal approximately equivalent to a combination of the digital signal and the combination of the quantized statistics of the one or more segments.

26. A method as recited in claim 25 further comprising normalizing amplitude of a digital signal, wherein such signal is an original, unmarked signal.

27. A method as recited in claim 25 further comprising transforming the signal.

28. A method as recited in claim 25, wherein the partitioning comprises pseudorandomly segmenting the signal.

29. A method as recited in claim 25, wherein the partitioning comprises pseudorandomly segmenting the signal, wherein such segments are adjacent and non-contiguous.

30. A method as recited in claim 25, wherein the statistics of the calculating comprises one or more finite order moments of a segment.

31. A method as recited in claim 25 further comprising determining a delta-sequence that is representative of the combination of the quantized statistics of the one or more segments.

32. A method as recited in claim 25 further comprising determining a pseudorandom delta-sequence that when combined with the digital signal approximate a combination of the digital signal and the quantized statistics of the one or more segments.

33. A method as recited in claim 25, wherein the generating comprises embedding a watermark via quantization index modulation (QIM).

34. A modulated signal generated in accordance with the acts recited in claim 25.

35. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 25.

36. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 25.

37. A method facilitating protection of digital signals, the method comprising:

partitioning a subject digital signal into segments;
for one or more segments:

- calculating statistics of a segment that are representative of that segment;
- quantizing such statistics of a segment to generated a quantized value of that segment;

determining whether a watermark is present in the digital signal based upon the quantized values of the one or more segments.

38. A method as recited in claim 37 further comprising:

normalizing amplitude of the subject digital signal;
transforming the normalized signal.

39. A method as recited in claim 37 further comprising:

for one or more segments, measuring the distance between such statistics of a segment and the quantized value of that segment;
determining an indication of confidence based upon the measured distances of the measuring;
indicating an indication of confidence.

40. A method as recited in claim 37 further comprising indicating whether a watermark is present.

41. A method as recited in claim 37 further comprising indicating whether a watermark is present, wherein such indication is selected from a group consisting of "present," "not present," and "unknown."

42. A method as recited in claim 37, wherein the partitioning comprises pseudorandomly segmenting the signal.

43. A method as recited in claim 37, wherein the partitioning comprises pseudorandomly segmenting the signal, wherein such segments are adjacent and non-contiguous.

44. A method as recited in claim 37, wherein the statistics of the calculating comprises one or more finite order moments of a segment.

45. A method as recited in claim 37, wherein the determining comprises detecting a watermark via quantization index modulation (QIM) techniques.

46. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 37.

47. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 37.

48. A method for facilitating the protection of digital signals, the method comprising

obtaining a digital signal;
obtaining a watermark;
using quantization index modulation (QIM), watermarking the signal with the watermark, wherein such QIM is

based upon non-local characteristics of the signal.

49. A method as recited in claim 48, wherein the non-local characteristics are representative characteristics of more than a single element of a signal.

50. A method as recited in claim 48, wherein the non-local characteristics comprise statistics representative of one or more segments of the signal.

51. A method as recited in claim 48, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly sized segments of the signal.

52. A method as recited in claim 48, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly dimensioned segments of the signal.

53. A method as recited in claim 48, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly dimensioned segments of the signal, wherein such segments are adjacent and non-contiguous.

54. A modulated signal generated in accordance with the acts recited in claim 48.

55. A modulated signal generated in accordance with the following acts:

providing a server computer in a communications with a communications network;
receiving input from a client computer by way of the communications network, the input providing a parameter indicative of a request for a modulated signal generated in accordance with the acts recited in claim 48;
generating the modulated signal in accordance with the acts recited in claim 48;
sending the modulated signal via the communications network.

56. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 48.

57. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 48.

58. A method for facilitating the protection of digital signals, the method comprising
obtaining a digital signal;
using quantization index modulation (QIM), detecting whether the signal includes a watermark, wherein such QIM is based upon non-local characteristics of the signal.

59. A method as recited in claim 58, wherein the non-local characteristics are representative characteristics of more than a single element of a signal.

60. A method as recited in claim 58, wherein the non-local characteristics comprise statistics representative of one or more segments of the signal.

61. A method as recited in claim 58, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly sized segments of the signal.

62. A method as recited in claim 58, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly dimensioned segments of the signal.

63. A method as recited in claim 58, wherein the non-local characteristics comprise statistics representative of one or more pseudorandomly dimensioned segments of the signal, wherein such segments are adjacent and non-contiguous.

64. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method as recited in claim 58.

65. A computer comprising one or more computer-readable media having computer-executable instructions that, when executed by the computer, perform the method as recited in claim 58.

66. A system for facilitating the protection of digital signals, the system comprising:

a partitioner configured to segment a digital signal;
a segment-statistics calculator configured to calculate statistics of a segment that are representative of that segment;
a segment quantizer configured to quantize such statistics of a segment
a signal marker configured to generate a marked signal approximately equivalent to a combination of the digital signal and the combination of the quantized statistics of the one or more segments.

67. A system as recited in claim 66, wherein the partitioner is further configured to pseudorandomly segment the signal.

68. A system as recited in claim 66, wherein the partitioner is further configured to pseudorandomly segment the signal, wherein such segments are adjacent and non-contiguous.

69. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method comprising:

obtaining a digital signal;
obtaining a watermark;
using quantization index modulation (QIM), watermarking the signal with the watermark, wherein such QIM is based upon non-local characteristics of the signal and the non-local characteristics are representative characteristics of more than a single element of a signal.

70. A computer-readable medium having computer-executable instructions that, when executed by a computer, performs the method comprising:

obtaining a digital signal;
using quantization index modulation (QIM), detecting whether the signal includes a watermark, wherein such QIM is based upon non-local characteristics of the signal and the non-local characteristics are representative characteristics of more than a single element of a signal.

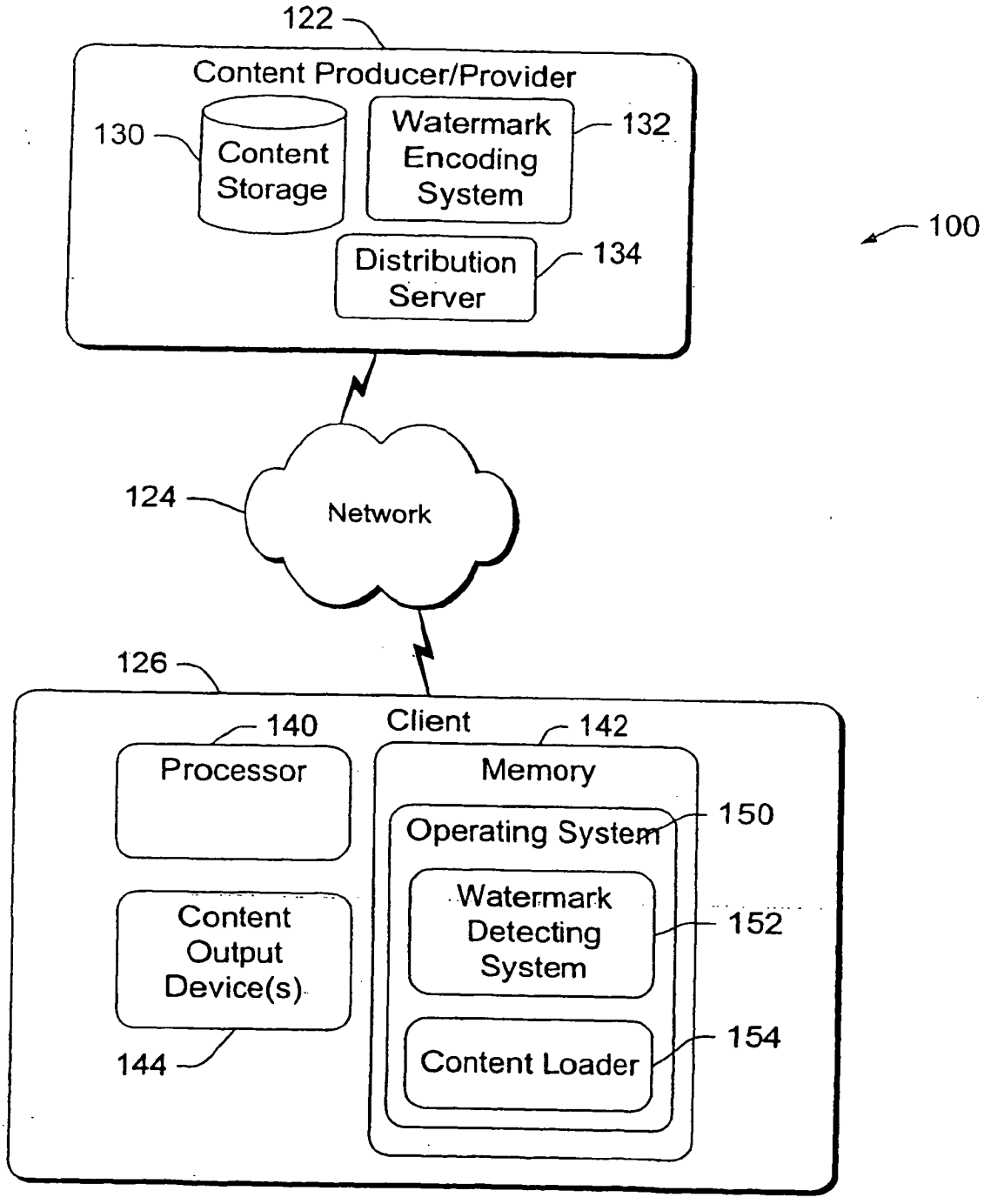
122
Content Producer/Provider
130
Content Storage
Watermark Encoding System
132
Distribution Server
134
100
124
Network
126
Client
140
Processor
142
Memory
Operating System
150
Watermark Detecting System
152
Content Output Device(s)
144
Content Loader
154

Fig. 1

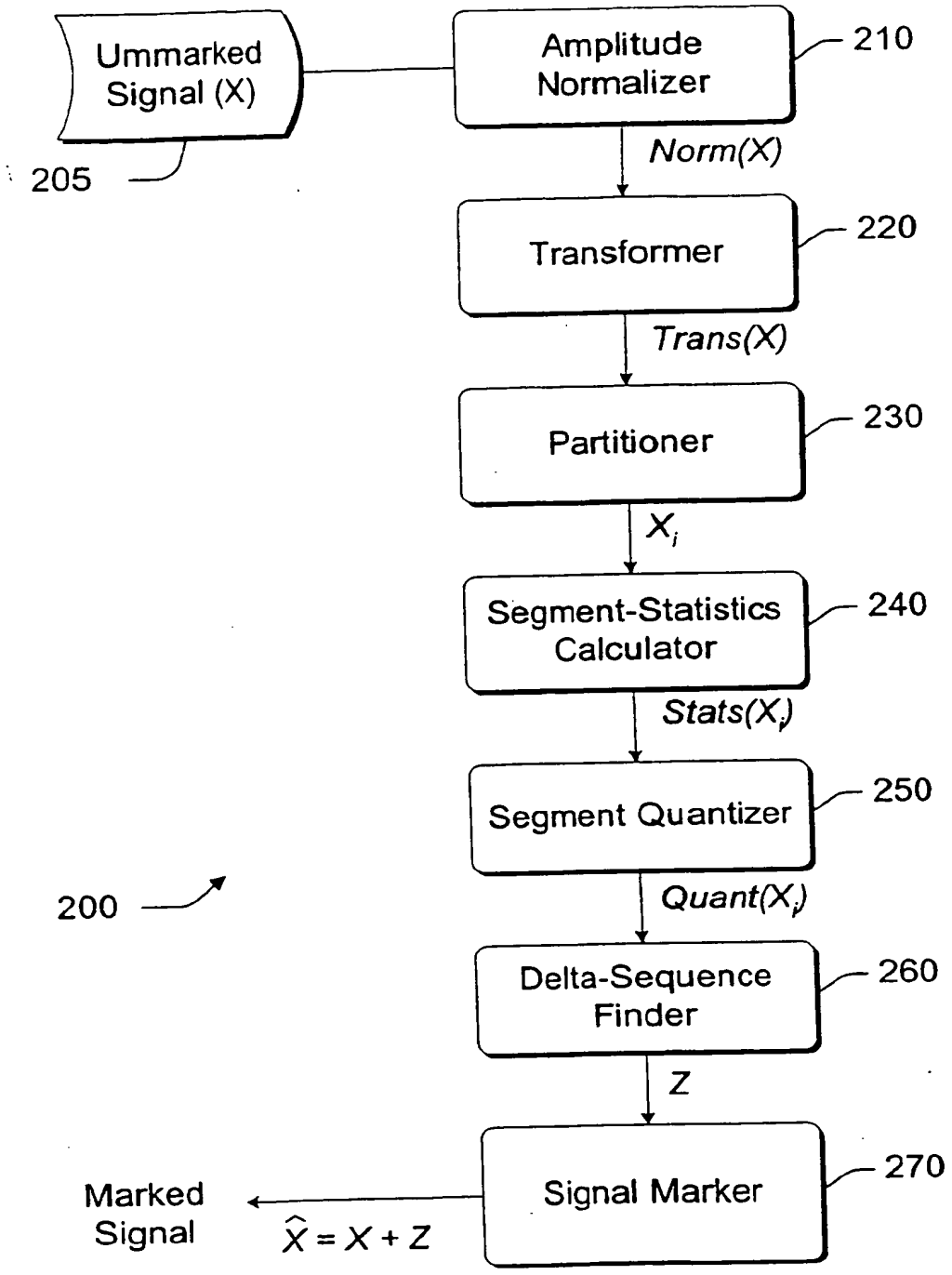
Ummarked Signal (X)
205
Amplitude Normalizer
210
Norm(X)
Transformer
220
Trans(X)
Partitioner
230
$X_i$
Segment-Statistics Calculator
240
Stats($X_i$)
Segment Quantizer
250
Quant($X_i$)
Delta-Sequence Finder
260
Z
Signal Marker
270
Marked Signal
$\hat{X} = X + Z$
200

Fig. 2

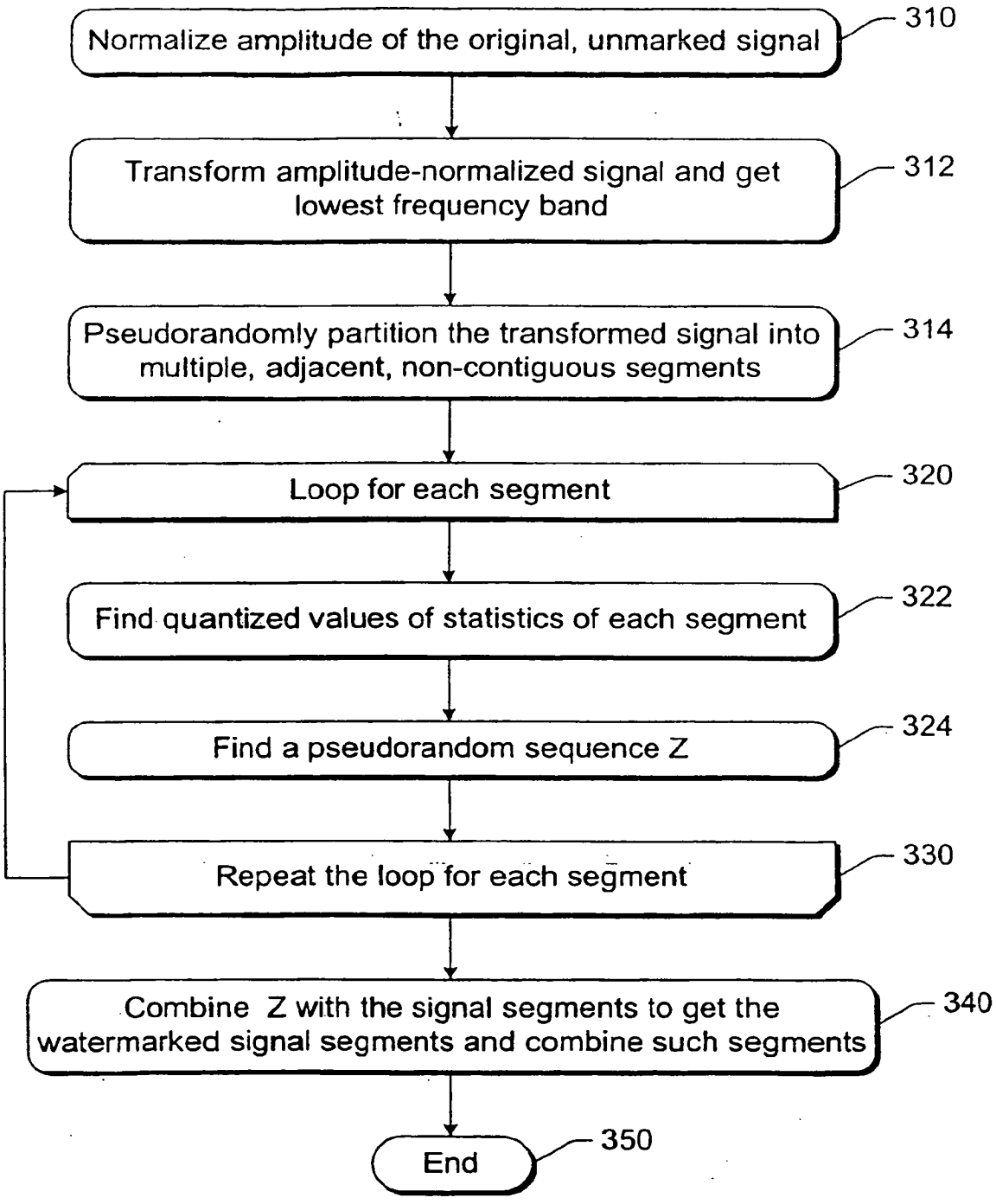
Normalize amplitude of the original, unmarked signal
310
Transform amplitude-normalized signal and get lowest frequency band
312
Pseudorandomly partition the transformed signal into multiple, adjacent, non-contiguous segments
314
Loop for each segment
320
Find quantized values of statistics of each segment
322
Find a pseudorandom sequence Z
324
Repeat the loop for each segment
330
Combine Z with the signal segments to get the watermarked signal segments and combine such segments
340
End
350

*Fig. 3*

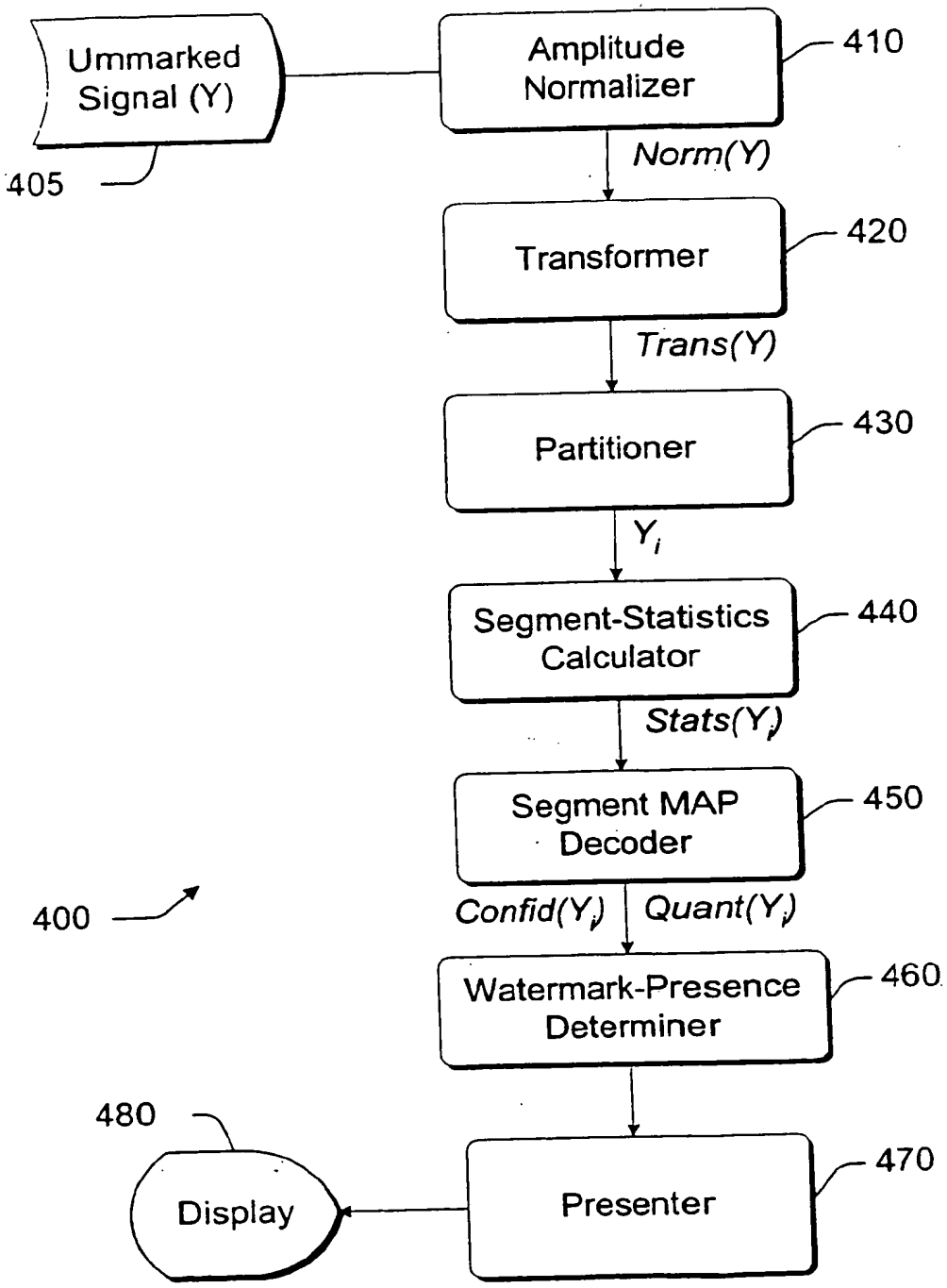
Ummarked Signal (Y)
405
Amplitude Normalizer
410
Norm(Y)
Transformer
420
Trans(Y)
Partitioner
430
$Y_i$
Segment-Statistics Calculator
440
Stats($Y_i$)
Segment MAP Decoder
450
400
Confid($Y_i$)
Quant($Y_i$)
Watermark-Presence Determiner
460
480
Display
Presenter
470

Fig. 4

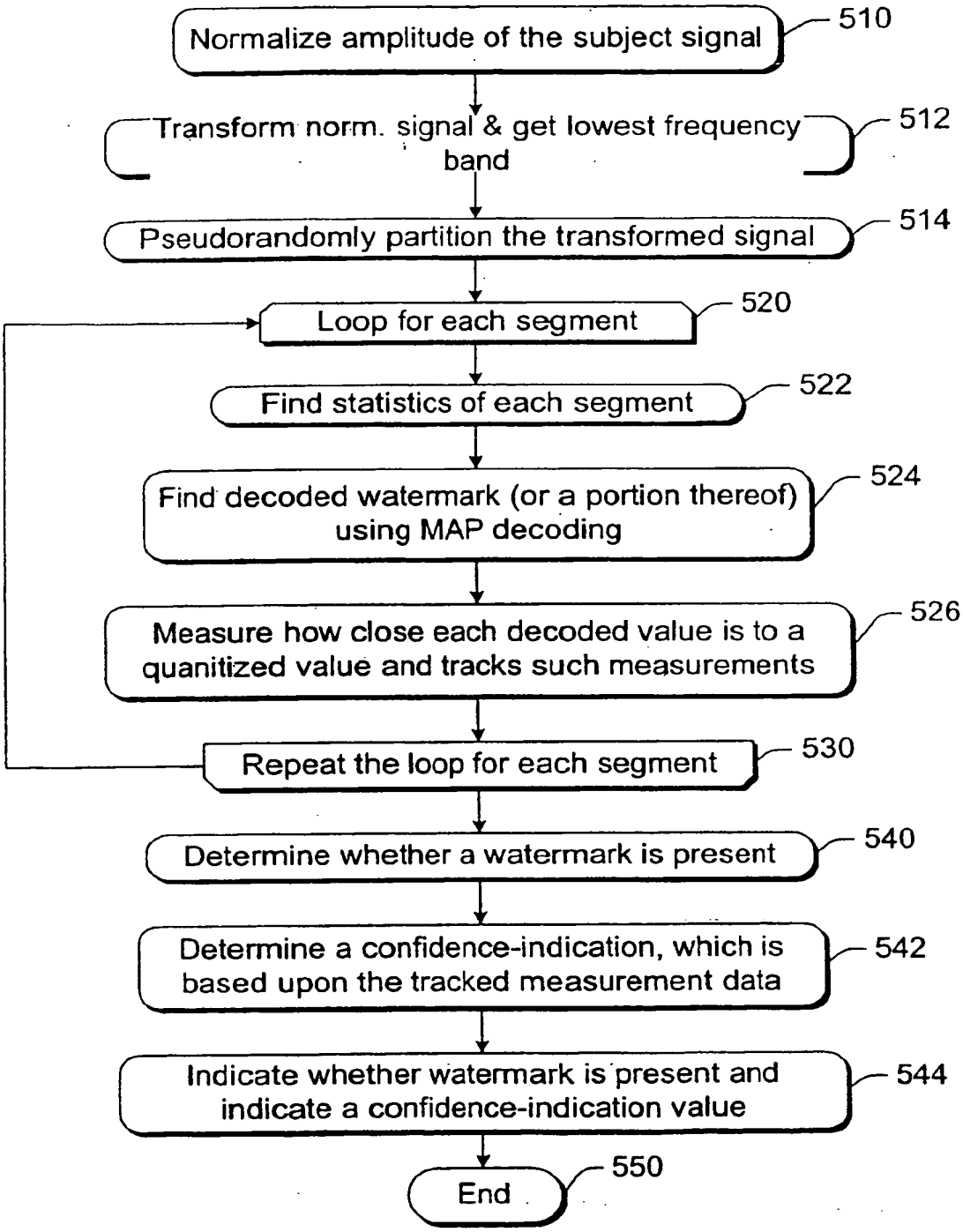
Normalize amplitude of the subject signal
510
Transform norm. signal & get lowest frequency band
512
Pseudorandomly partition the transformed signal
514
Loop for each segment
520
Find statistics of each segment
522
Find decoded watermark (or a portion thereof) using MAP decoding
524
Measure how close each decoded value is to a quanitized value and tracks such measurements
526
Repeat the loop for each segment
530
Determine whether a watermark is present
540
Determine a confidence-indication, which is based upon the tracked measurement data
542
Indicate whether watermark is present and indicate a confidence-indication value
544
End
550

*Fig. 5*

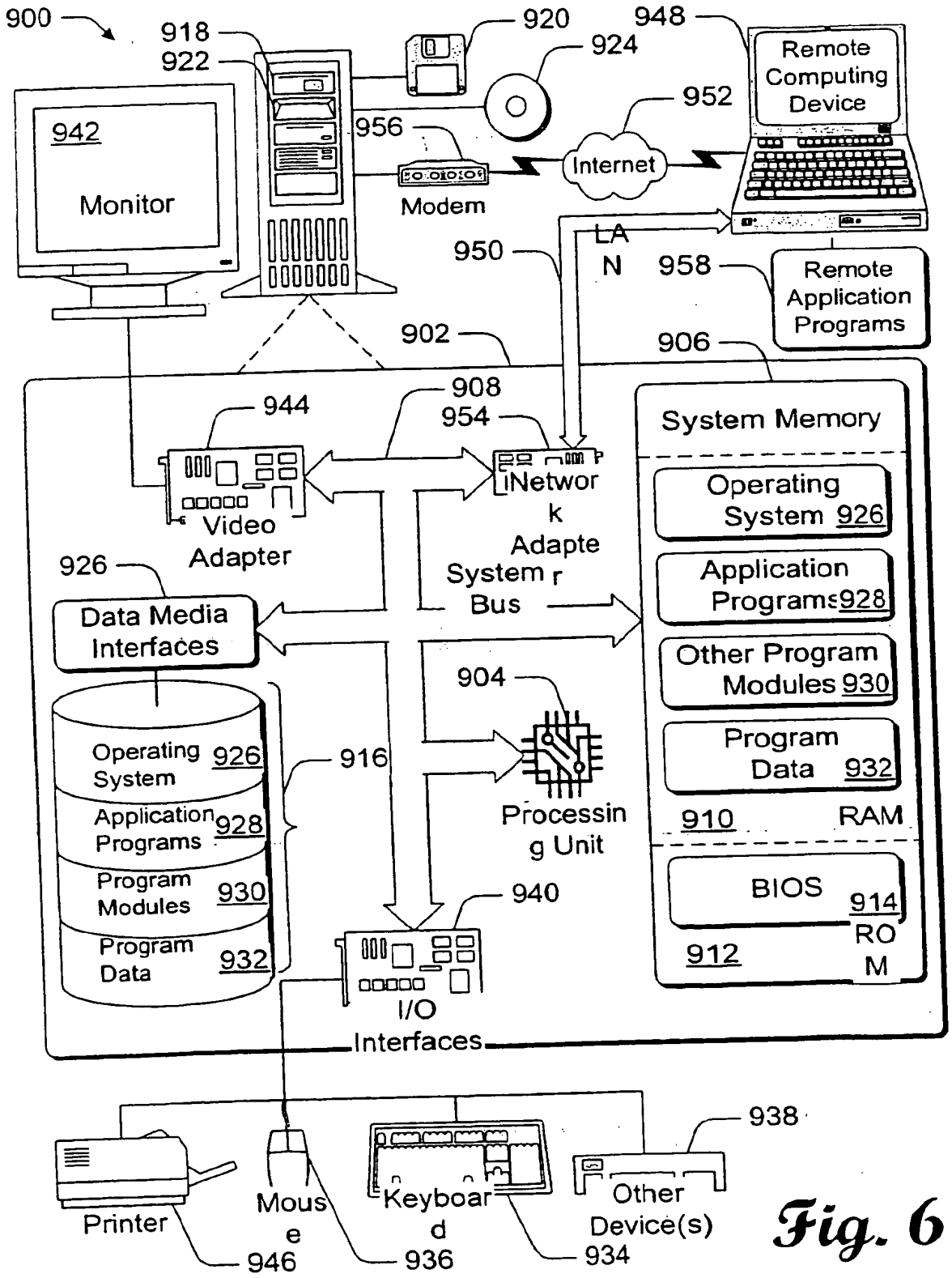
900
918
922
920
924
948
Remote Computing Device
952
942
Monitor
956
Modem
Internet
LAN
950
958
Remote Application Programs
902
906
944
908
954
System Memory
Network Adapter
Video Adapter
System Bus
926
Data Media Interfaces
Operating System 926
Application Programs 928
Other Program Modules 930
Program Data 932
904
916
Processing Unit
910
RAM
BIOS 914
912
ROM
940
I/O Interfaces
938
Printer
946
Mouse
936
Keyboard
934
Other Device(s)

Fig. 6

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European Patent Office
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## (54) Derivation and quantization of robust non-local characteristics for blind watermarking

(57) An implementation of a technology is described herein for deriving robust non-local characteristics and quantizing such characteristics for blind watermarking of a digital good. This technology finds the proper balance between minimizing the probability of false alarms (i.e., detecting a non-existent watermark) and the probability of misses (i.e., failing to detect an existing watermark). The technology described herein, performs quantization index modulation (QIM) based upon non-local characteristics of the digital good. Non-local characteristics may include statistics (e.g., averages, median) of a group of individual parts (e.g., pixels) of a digital good. This abstract itself is not intended to limit the scope of this patent. The scope of the present invention is pointed out in the appending claims.

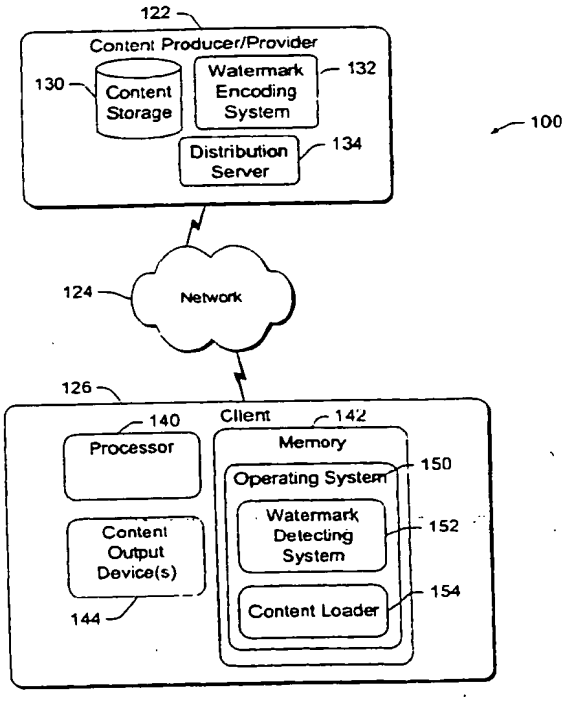


Fig. 1

EP 1 253 784 A3

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number
EP 02 00 6202

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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
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| Y | WO 99 60514 A (MASSACHUSETTS INST TECHNOLOGY) 25 November 1999 (1999-11-25) * the whole document * | 1-70 | |
| A | CHEN B ET AL: "Achievable performance of digital watermarking systems" MULTIMEDIA COMPUTING AND SYSTEMS, 1999. IEEE INTERNATIONAL CONFERENCE ON FLORENCE, ITALY 7-11 JUNE 1999, LOS ALAMITOS, CA, USA,IEEE COMPUT. SOC, US, 7 June 1999 (1999-06-07), pages 13-18, XP010342868 ISBN: 0-7695-0253-9 * the whole document * | 1-70 | |
| A | CHEN B ET AL: "QUANTIZATION INDEX MODULATION METHODS FOR DIGITAL WATERMARKING AND INFORMATION EMBEDDING OF MULTIMEDIA" JOURNAL OF VLSI SIGNAL PROCESSING SYSTEMS FOR SIGNAL. IMAGE, AND VIDEO TECHNOLOGY, KLUWER ACADEMIC PUBLISHERS, DORDRECHT, NL, vol. 27, no. 1/2, February 2001 (2001-02), pages 7-33, XP001116257 ISSN: 0922-5773 * the whole document * | 1-70 | TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04N G06T G11B |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| MUNICH | 11 April 2003 | Luckett, P |

CATEGORY OF CITED DOCUMENTS

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D : document cited in the application
L : document cited for other reasons

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EPO FORM 1503 03.02 (P04C01)

## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 02 00 6202

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11-04-2003

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| | | US 2001033674 A1 | 25-10-2001 |
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| | | EP 1093635 A1 | 25-04-2001 |
| | | JP 2002516414 T | 04-06-2002 |
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